§8. Reversal of Intrinsic Rotation and Torque Driven by ECH in LHD Plasmas

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The reversal of totoidal flow during the density scan and the change in rotation during ECH phase have been widely observed in many tokamaks. The change of the sign of the residual stress is one of the strong candidates of mechanism causing these phenomena. It is important to evaluate the intrinsic torque experimentally to test the theoretical model of intrinsic toque. In experiment the decreases of co-rotation by ECH have been widely observed in tokamaks. However, it has been a open to question whether the effect of ECH is damping due to the enhanced MHD activity or driving due to residual stress to the couter- direction. In LHD a clear reversal of toroidal flow from co-rotation to counter-rotation is observed associated with the ECH, which is a clear evidence of the residual stress driven by ECH.

Figure 1 shows the radial profiles of toroidal rotation in the NBI (co-injection) with ITB and NBI + ECH plasmas. The central rotation changes its sign from co- to counter-rotation and significant hollow rotation profile is observed during the ECH. This observation clearly shows that the effect of ECH is not damping the rotation but driving rotation in counter-direction. In order to evaluate the intrinsic torque driven by ECH, a relation between the normalized external torque and velocity gradient is evaluated. The difference of normalized momentum flux from the slope of $\mu_\phi = 5$ m^2/s, which is driven by NBI discharge, gives quantitative evaluation of normalized momentum flux (1.3 $\times 10^6$m^{2}s^{-2}) driven by the intrinsic torque in counter-direction. It should be noted that the central rotation is in the counter-rotation, although the external torque is only co-injection NBI. The hollow rotation profiles observed shows that the intrinsic toque due to ECH is highly localized near the magnetic axis, where the significant increase of electron temperature exists. The counter-torque driven by ECH exceeds the co-torque driven by NBI.

The intrinsic torque and change in momentum flux are evaluated in the plasma, where a reversal of intrinsic torque is observed during the formation of ITB and ECH. The intrinsic torque in the ITB plasma ($T_i > T_e$) is in the co-direction[1)], while the intrinsic torque in the NBI + ECH plasma ($T_i \sim T_e$) is in the counter-direction. These experiments demonstrate that the sign of the intrinsic rotation is reversed depending on the ion/electron temperature ratio, which causes the change in turbulence mode in the plasma.

1) K.Ida et. al., Phys. Rev. Lett. **111** (2013) 055001.

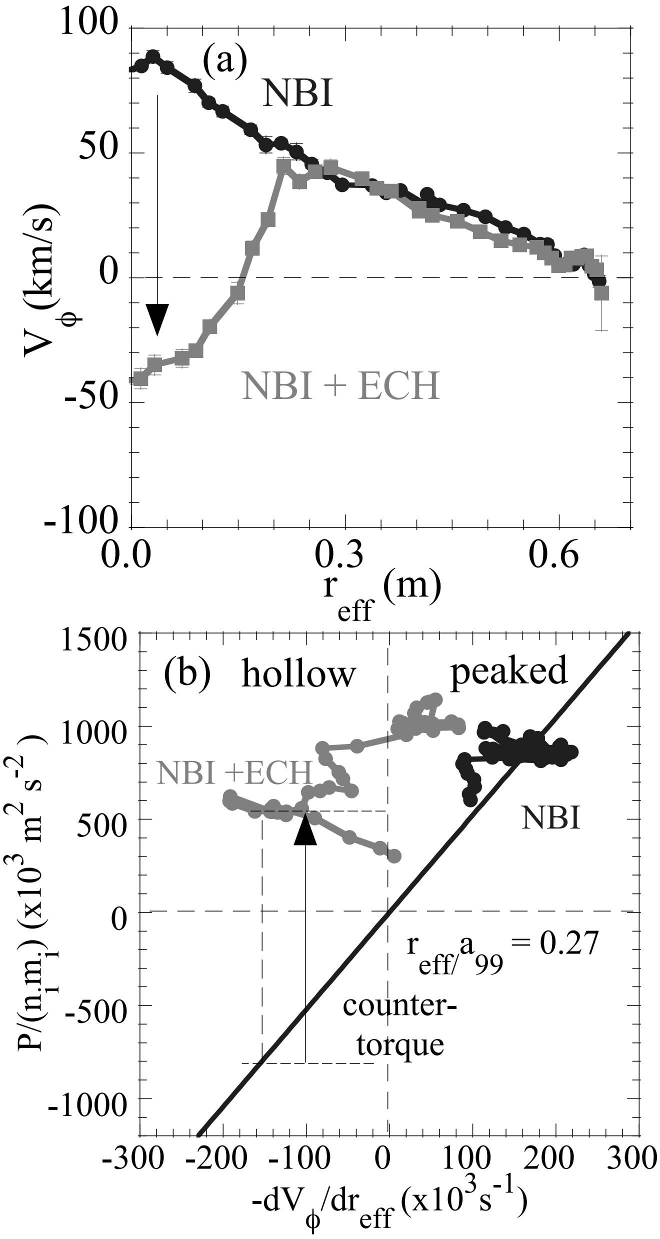

Fig. 1: (a) Radial profile of toroidal rotation velocity in the co-injection NBI discharge and co-injection NBI+ECH discharge. The reverse of central toroidal rotation from co- to counter-direction and hollow rotation profile are observed by applying center focused ECH. (b) Normalized external torque vs velocity gradient in the co-injection NBI discharge and co-injection NBI + ECH discharges at the normalized plasma minor radius of 0.27. The intrinsic torque driven by ECH is in the counter- direction and exceed the torque driven by tangential NBI.